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BIOLOGICAL CONTROL

Effects of Food Deprivation on the Development of *Coleomegilla maculata* (De Geer) (Coleoptera: Coccinellidae)

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Abstract

The lady beetle *Coleomegilla maculata* (De Geer) is a natural enemy of several insect pests and feeds on pollen and nectar to survive periods when prey is scarce. The effect of the feeding interval on the development, survival, fecundity, and longevity of *C. maculata* was determined. Newly hatched larvae of *C. maculata* were reared individually and fed with eggs of the Mediterranean flour moth *Anagasta kuehniella* (Zeller) at intervals of one, two, and three days under controlled conditions (23 ± 1ºC; 60 ± 10% RH; 12 h phtophase). The duration of larval instars and the total larval stage was prolonged as the feeding interval increased. The larval period lasted on average 9.2 ± 0.19 days when the larvae were fed daily with prey, and 14.6 ± 0.48 days when food was offered at three-day intervals. There was an inverse relationship between food intervals, survival, and weight of larvae and adults of the coccinellid. Survival rate of larvae fed daily was 76.8%, while the rate was 50.0% and 23.4% for larvae fed every two and three days, respectively. *Coleomegilla maculata* showed fecundity of 781.1 ± 149.02, 563.4 ± 80.81 and 109.0 ± 103.0 eggs when fed daily and at intervals of two and three days, respectively.

Introduction

Agricultural ecosystems contain large numbers of predatory insects and Coccinellidae represents 90% of such beneficial insects that act as natural controls of insect pests (Iperti 1999, Musser & Shelton 2003).

The lady beetle *Coleomegilla maculata* (De Geer) is widely distributed in Canada, in the United States, and in Central and South America (Gordon 1985). It is a natural enemy of aphids, mites, and eggs and larvae of coleopterans and lepidopterans (Hodek 1973, Weeden *et al* 2007), and also feeds on pollen and nectar to survive periods when prey is scarce (Hodek & Honek 1996, Lundgren *et al* 2004).

Studies on the development and reproduction of *C. maculata* have been determined on several kind of diets such as eggs of *Anagasta kuehniella* (Zeller) (Lepidoptera: Pyralidae), aphids as *Aphis gossypii* Glover and *Schizaphis graminum* Rondani (Hemiptera: Aphididae) (Rondon *et al* 2006, Michaud & Jyoti 2008) and pollen (Michaud & Grant 2005, Pilorget *et al* 2010). However, Lundgren *et al* (2004) pointed out that *C. maculata* reaches the adult stage and it is able to reproduce on a diet composed solely of pollen and water.

The ability to survive and reproduce even in periods of prey scarcity is one characteristic that qualifies an efficient predator (Declercq & Degheele 1992). Therefore, this important attribute must be considered when choosing insect predators for use as pest-control agents (Nakashima & Hirose 1999).

Scarcity of prey can adversely affect the development, survival, and fecundity of lady beetles (Obrycki *et al* 1998, Agarwala *et al* 2001, Schüder *et al* 2004), and food deprivation seems to differently affect each insect species (Phoofolo *et al* 2008, 2009).

In agroecosystems, coccinellids are subject to alterations in prey availability according to biotic and abiotic factors (Phoofolo *et al* 2008). Prey availability in the ecosystems is an important factor that influences the development and growth of coccinellids, reducing their adult size, what can affect their potential as predators and thus influence their efficiency as biological control agents (Agarwala *et al* 2008, Phoofolo *et al* 2009). In the present study, we determined the effect of the feeding interval on larval performance and reproductive traits of *C. maculata* in the laboratory by offering prey at intervals of one, two and three days. This information can contribute in the evaluation of the potential of this predator as a biological control agent.

Material and Methods

Adults of *C. maculata* were collected in a cornfield in Andradina municipality, São Paulo state, Brazil. The insects were transferred to the laboratory and kept in five pairs in containers (10 cm high by 10 cm diameter). Each container was covered internally with sulfite paper as a substrate for egg laying. The adults were given eggs of *Anagasta kuehniella* (Zeller) (Lepidoptera: Pyralidae) as a food source disposed at the bottom of the cage along with inflorescences of sorghum and a mixture of yeast and honey (1:1) brushed on a strip of Parafilm®. Water was supplied by moistened cotton placed in 10ml jars. The internal covering of the containers was changed daily, and the eggs were kept in Petri dishes (12 cm in diameter). The newly hatched larvae were fed with A. *kuehniella* eggs until pupation.

To evaluate the development of *C. maculata*, newly hatched larvae were isolated and fed with *A. kuehniella* eggs offered at intervals of one, two, and three days. The amount of eggs offered in each one of these intervals was 3.0 ± 0.10 mg, 5.5 ± 0.29 mg, 11.6 ± 0.69 mg, 24.5 ± 1.52 mg and 16.4 ± 0.94 mg, respectively, for first, second, third and fourth instars and adults. Each experimental unit consisted of a glass tube (8 cm in height by 2.5 cm in diameter) containing one individual of the predator and the prey eggs. The number of larvae assigned to each treatment was 30, with each larva being considered a replicate. The insects were kept under controlled conditions (23 ± 1°C, 60 ± 10% RH, 12h photophase). The following biological parameters were evaluated: duration and survival of each instar; fresh weight of larvae at six and eight days of age; and duration and survival of the larval, pupal, and larva-adult stages.

In the adult stage the lady beetles were fed at the same intervals as the larvae. Pairs of *C. maculata* were tested for the feeding intervals of one and of two days. Only two pairs of adults originated from larvae subjected to feeding at three day intervals. The adult insects were weighed 24h after emergence and were observed daily to evaluate the pre-oviposition, oviposition, and post-oviposition periods, daily and total egg-laying capacity, and longevity.

To evaluate the young and adult stages, we used a completely randomized design and submitted the data to analysis of variance and whenever differences were detected, averages were compared by the Tukey test ($P \leq 0.05$).

Results and Discussion

Except for the first instar, the duration of the remaining instars of *C. maculata* increased with the feeding interval. Larvae fed daily remained longer in the first instar than did those fed with *A. kuehniella* eggs at two-day intervals. However, there was no statistically significant difference in the duration of the first instar between the larvae fed at intervals of one and three days (Table 1).

The *C. maculata* larvae fed at three-day intervals had longer development periods from the second to the fourth instars (Table 1). The variation in duration of the instar as a function of the feeding interval was more pronounced in the fourth instar. This probably occurred because during this instar the predator consumes more prey than in the previous ones (Lanzoni *et al* 2004), what may represent 80% of their total prey consumption (Hodek & Honek 1996).

Phoofolo *et al* (2008) reported similar results in relation to this study. These authors evaluated the development of coccinellid *H. axyridis* during the fourth instar when fed with the aphid *S. graminum* at intervals of one, two, three, four, and five days. They observed that the development time of this stadium increased significantly with the period of food restriction.

In the present study, the development time of the larval and larval-adult stages of *C. maculata* lengthened as the feeding interval increased, but the pupal period was not influenced by the feeding interval to which the predator was submitted (Table 1), as observed for *C. maculata*, *H. convergens,* and *H. axyridis* (Phoofolo *et al* 2008).

Coleomegilla maculata larvae offered prey daily, developed 1.1 and 5.4 days faster when compared to larvae fed at two- and three-day intervals, respectively (Table 1).

Table 1 Mean duration (days) and survival (%) (± SE) of the developmental phases of *Coleomegilla maculata* fed with eggs of *Anagasta kuehniella* offered at different intervals. Temp.: 23 ± 1 ºC, RH: 60 ± 10%, and photophase: 12h.

Feeding interval (days)	1st instar		2nd instar		3rd instar		4th instar	
	Duration	Survival[ns]	Duration	Survival	Duration	Survival[ns]	Duration	Survival[ns]
1	3.1 ± 0.16 a	87.0 ± 9.72	1.7 ± 0.12 a	100.0 a	1.8 ± 0.11 a	96.7 ± 3.33	2.8 ± 0.09 a	93.4 ± 6.60
2	2.2 ± 0.10 b	87.0 ± 6.20	2.2 ± 0.15 a	85.0 ± 7.43 ab	2.2 ± 0.22 a	80.4 ± 8.33	3.5 ± 0.32 a	90.0 ± 10.00
3	3.2 ± 0.15 a	80.0 ± 12.24	2.7 ± 0.41 b	63.0 ± 11.03 b	3.4 ± 0.42 b	82.0 ± 11.13	5.3 ± 0.42 b	93.4 ± 6.66

Feeding interval (days)	Larva		Pupa		Larva-Adult	
	Duration	Survival	Duration[ns]	Survival[ns]	Duration	Survival
1	9.2 ± 0.19 a	76.8 ± 9.97 a	3.0 ± 0.20	100.0 ± 0.00	12.2 ± 0.20 a	76.8 ± 10.00 a
2	10.3 ± 0.45 b	50.0 ± 11.78 ab	3.3 ± 0.27	83.4 ± 10.00	13.6 ± 0.38 b	50.0 ± 14.91 ab
3	14.6 ± 0.48 c	23.4 ± 11.60 b	3.3 ± 0.28	60.0 ± 18.70	17.9 ± 0.42 c	23.4 ± 2.67 b

Means followed by the same letter in the column do not differ by the Tukey test at 5% significance; ns = non significant.

The lengthening of the development period is a mechanism that allows insects to survive to inadequate nutrition during the larval stage, as it allows insects to extend their feeding activity to acquire enough food resources to complete growth (Shafiei *et al* 2001). Probably, if *C. maculata* has a prolonged larval stage under field conditions, this should provide more opportunity to the coccinellid to find and consume large quantities of prey. However, it is not advantageous to prolong pupal stage due to an increase in mortality risk by natural enemies and/or weight loss (Phoofolo *et al* 2008).

The survival of *C. maculata* instars was not significantly influenced by the feeding interval, except for the second instar (Table 1). However, survival during the larval and larval-adult stages was lower for specimens fed at three-day intervals in comparison with those fed daily. During larval development, survival rate was 76.8% when fed daily, while 50.0% when fed every two days. Under conditions of food availability at intervals of three days, the amount of prey consumed by *C. maculata* larvae was not sufficient to promote development and growth, since only 23.4% reached the adult stage. According to Schüder *et al* (2004), lady beetle larvae react to a shortage of food by developing more slowly, but a lower amount of food increases mortality at all immature stages. Obrycki *et al* (1998) also reported lower survival rates of *C. maculata* as a function of food deprivation. According to them, when *C. maculata* larvae were offered 20 individuals per day of the pea aphid *A. pisum*, 86% of them survived, but when they were only provided with one aphid a day, the survival rate fell to 63%.

The weight of *C. maculata* decreased as the feeding interval increased (Fig 1). Larvae submitted to intervals of two and three days without feeding were lighter, with the heaviest larvae (9.0 mg and 20.0 mg, respectively) occurring at six and eight days of age daily fed with *A. kuehniella* eggs. Fourth instars showed a particularly increase in body weight, even in conditions of scarcity of food, because of their need to store energy for pupation.

The adults weight decreased with the feeding interval (Fig 1) as observed when the species was fed aphids as prey, with shortage of food during the larval stage being the a possible cause of the reduced size of predators, including that observed under natural conditions in agricultural ecosystems (Obrycki *et al* 1998).

Adults of *C. maculata* fed at one and two day intervals did not show any significant difference with respect to the pre-oviposition, oviposition, and post-oviposition periods (Table 2). Also, we did not find any significant difference in the fecundity and longevity of *C. maculata* as a function of food deprivation at two tested feeding intervals. Females with availability of prey at intervals of two days, besides a lower body mass, showed fecundity similar to females that were prey-fed daily (Table 2). Only four *C. maculata*

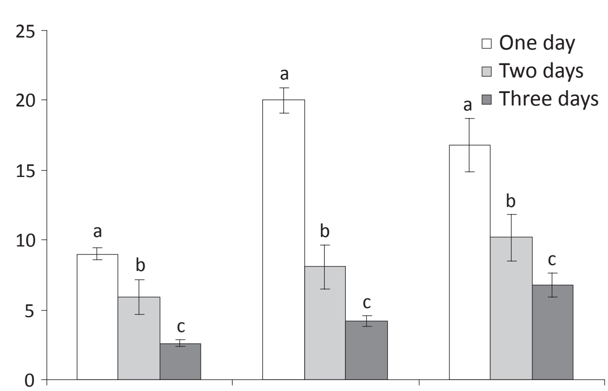

Fig 1 Mean weight (mg) of larvae at six days (L6) and eight days (L8) of age and adults of *Coleomegilla maculata* fed with eggs of *Anagasta kuehniella* offered at intervals of one, two and three days.

Table 2 Mean duration of longevity (days) and fecundity (± SE) of *Coleomegilla maculata* fed with eggs of *Anagasta kuehniella* offered a different intervals. Temp.: 23 ± 1 ºC, RH: 60 ± 10%, and photophase: 12h.

Feeding interval (days)	Pre-oviposition	Oviposition	Post-oviposition	Fecundity		Longevity	
				Daily	Total	Females	Males
1	3.4 ± 0.56	82.3 ± 16.47	15.9 ± 7.83	10.9 ± 1.68	781.1 ± 149.02	105.6 ± 16.67	63.5 ± 12.81
2	3.6 ± 0.87	108.6 ± 12.31	8.8 ± 3.33	5.3 ± 0.61	563.4 ± 80.81	129.4 ± 13.81	100.8 ± 17.71

Means in the columns did not differ by F test at 5% significance.

larvae fed at three day intervals reached adult stage, resulting in two couples. Therefore, no statistical analysis was performed. In this treatment, the pre-oviposition, oviposition and post-oviposition periods were 66.0 ± 17.0; 52.0 ± 51.0 and 9.0 ± 3.33 days, respectively. Longevity of females was 125.5 ± 30.5 days and 37.0 ± 29.0 days for males; daily and total fecundity were 4.0 ± 1.97 eggs and 109.0 ± 103.0 eggs, respectively.

When the coccinellid was supplied with prey at two and three day intervals, larval stage was prolonged and the weight of larvae and adults were reduced. However, under these conditions of food restriction the predator demonstrated ability to survive and reproduce. These characteristics are important as coccinellids that feed on aphids live in habitats with seasonal variations in prey availability, since aphid populations are ephemeral (Agarwala *et al* 2008). Yet, the ability to survive and complete development when deprived of food is an indication of an important adaptive strategy that should allow lady beetles to cope with the highly unpredictable and variable food resources in nature (Phoofolo *et al* 2008).

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